Determination of the Spatial Variation of the Atmosphere and Ocean Wave Fields in Extremely Light Wind Regimes

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LONG-TERM GOALS

Existing parameterizations of heat, moisture, and momentum fluxes in the marine atmospheric boundary layer (MABL) perform poorly under weak wind regimes, especially in regions of inhomogeneity. These problems are due to a variety of processes (e.g., averaging techniques, gravity capillary wave spacing, surfactants and surface tension, free convection effects, frequency-dependent differences between wind, waves, and stress). In order to address these various forcing mechanisms, high-resolution, high-fidelity atmospheric and surface wave data are needed to describe energy exchange across the air-sea interface. The overall long-term goal of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) low-wind initiative is to acquire these data in order to better understand air-sea interaction in extremely light wind regimes.

OBJECTIVES

The objective is to advance our understanding of the processes that control the exchange of heat, moisture, and momentum across the air-sea interface. More specifically, we will (1) measure vertical fluxes of momentum and heat in the MABL and in the ocean surface layer; (2) identify the processes that influence these fluxes; (3) close budgets for heat and momentum; (4) test parameterizations of fluxes; and (5) obtain other measurements sufficient to provide boundary conditions for a large eddy simulation or local application of a regional-scale simulation.

APPROACH

The LongEZ (registration N3R) research aircraft has been used extensively to acquire data for a variety of air quality and environmental research projects (Fig.1). Because of its clean aerodynamics and advanced instrument systems, this aircraft has proven to be especially powerful in studying the

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14. ABSTRACT

Existing parameterizations of heat, moisture, and momentum fluxes in the marine atmospheric boundary layer (MABL) perform poorly under weak wind regimes, especially in regions of inhomogeneity. These problems are due to a variety of processes (e.g., averaging techniques, gravity capillary wave spacing, surfactants and surface tension, free convection effects, frequency-dependent differences between wind, waves, and stress). In order to address these various forcing mechanisms, high-resolution, high-fidelity atmospheric and surface wave data are needed to describe energy exchange across the air-sea interface. The overall long-term goal of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) low-wind initiative is to acquire these data in order to better understand air-sea interaction in extremely light wind regimes.

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MABL and air-sea exchange processes. The instrument suite and data acquisition system are used to measure mean properties of the atmosphere as well as turbulent fluxes of heat, moisture, and momentum. Remote sensors are used to characterize ocean wave properties. Data acquired by N3R will support the test and refinement of parameterizations used in air-sea models. These measurements will provide important boundary conditions to determine the processes controlling the exchange of energy across the air-sea interface.

Fig. 1. Photo N3R during a research mission.

Various *in situ* and remote sensors are employed by N3R for the measurement of atmospheric and wave field properties. The "best" aircraft turbulence (BAT) probe is used to acquire high-frequency wind, temperature, and pressure. An open-path infrared gas analyzer measures turbulent fluctuations in water vapor. Upward and downward radiometers are also employed to acquire short and long wave radiation. Global positioning system (GPS) technology provides precise position, velocity, attitude, and time. A laser altimeter array and a Ka-band scatterometer are used to determine long and short wave characteristics, respectively, of the sea surface. The lasers are used to measure wave height and directional wave spectra for wavelengths greater than 3 m. The scatterometer is used to estimate the integrated surface roughness of short-scale waves by measuring the intensity of quasi-specular backscatter. The backscatter signal strength is related to the mean-square-slope of the sea surface for wavelengths from 1 to 100 cm.

WORK COMPLETED

This research initiative requires highly accurate measurements from a very stable measurement platform. Although we have been successful in obtaining high-fidelity measurements from N3R in past field studies, resolving weak signals in the low-wind MABL will place special demands on the aircraft measurement system. Therefore, upgrades to several components were necessary to meet the accuracy requirement demanded by the proposed work.

The accuracy of wind velocity measurements acquired by N3R is determined by how well aircraft ground velocity is measured. Using differentially-corrected GPS methods, the previous system was accurate to within a few cm s^{-1}, which under normal conditions, is sufficient for most applications. However, greater accuracy is desirable for flights when mean winds and turbulent intensities are quite small. Recent advances in GPS technology have decreased the uncertainty in measurements of aircraft velocity by nearly an order of magnitude. This was accomplished by installing new GPS receivers utilizing both pseudo-range and phase information for two frequency bands (L1 and L2).

Accurate air-sea temperature measurements are critical for understanding the physics of sensible heat flux. While there is a long history of using various infrared (IR) sensors to estimate sea surface temperature (SST), overall accuracies have been unimpressive. Drifts in SST data acquired by an Everest 4000.4GXL IR sensor employed by N3R have been linked to changes in the body temperature of the instrument. This was first suspected during the Shoaling Waves Experiment (SHOWEX) when ambient air temperatures (thus sensor body temperature) were near freezing in the morning at the start of a flight and up to 20 °C by late morning to early afternoon when N3R completed its mission. Laboratory testing showed that accurate SST measurements could be improved if the body temperature of the probe could be kept at a constant temperature. A temperature controller and an insulated flexible heater were purchased. The flexible heater was wrapped around the body of the IR sensor and encased with a layer of insulation. In addition, a second-order polynomial calibration curve replaced a simple linear regression.

A laser altimeter array and a nadir-pointing Ka-band (0.8 cm) scatterometer are used to determine long and short wave characteristics, respectively, of the sea surface. The data obtained from these remote sensors is unique in that it provides wave information from small capillary waves to long swells coupled with wind stress and turbulence measurements in the atmospheric surface layer.

Light wind and low sea state conditions expected in CBLAST-Low necessitate improvements in the aircraft's laser altimeters. Small horizontal variations in the intermediate-scale wave slope field need to be better resolved. The small slopes and relative shift of energy towards shorter wave scales (~5 to 100 cm) at light winds suggest that the laser altimeters be sampled at even faster rates. In previous air-sea studies, the three lasers operated at a pulse repetition frequency of 2 KHz. Thirty-eight individual pulses were averaged down to a rate of 50 Hz to reduce contamination from noise. Such a measurement requires roughly 20 ms, during which time N3R has traveled a distance of approximately 1 m. As a result, shorter waves (wavelengths on the order of a few meters) are washed out by this averaging effect. For CBLAST-Low, one of the lasers was replaced with a similar but faster high-speed laser (12 KHz) which could acquire more instantaneous values of wave slope. In addition, the pulses from all three lasers are now averaged down to a rate of 150 Hz. These upgrades have improved the signal-to-noise ratio by a factor of three and resolved smaller scale waves. In addition, the 2-KHz laser that was replaced with its 12-KHz counterpart was mounted in N3R at 15° from the vertical. This 15° laser is now being used as a "glint" meter to resolve very small wave slopes.

A new nadir-pointing Ku-band (2.3 cm) scatterometer is being developed to operate alongside the existing Ka-band sensor expressly for support of the light wind observations. Differences of the two backscatter signals will help resolve the smaller scale parasitic capillary waves that are important to dissipation under light winds. Dual-frequency TOPEX altimeter satellite studies have shown that a C- and Ku-band nadir-viewing combination provides a useful tool for probing these characteristics at light wind speeds. The Ku-band scatterometer will have a single 30-cm microstrip aperture and will collect data from the same footprint and at the same time as that of the Ka-band sensor.

Because of its highly controllable and stable flight characteristics, N3R is routinely flown at 10 m above the ocean surface. However, the light-wind MABL can be quite shallow, possibly less than 50 m in some cases. Near-surface flux measurements are critical because the constant flux layer is often limited to the lower 10% of the MABL. Turbulence intensity levels are expected to be rather weak and intermittent in the light-wind MABL. In addition, ocean wave characteristics are expected to be more "confused" since wind stress levels will be quite small. These reduced energies make high-fidelity measurements more difficult. By dynamically stabilizing aircraft altitude and attitude, the dramatic reduction in platform motion will enhance the utility and quality of many observations. The dynamic stabilization proposed will allow lower (<10 m) flight altitude and important reduction in altitude, pitch and roll variance. Improved aircraft stabilization will dramatically improve all *in situ* and remote sensor measurements. To accomplish the dynamic stabilization, two novel modifications to the autopilot system were implemented. First, the pressure transducer used for altitude reference was supplemented with a slow response laser altimeter. Input from the more precise laser should reduce the variance in aircraft altitude. Second, a second-order high-gain feedback was added to improve control of the aircraft roll angle. By imposing the negative of the first derivative of roll angle, the autopilot computer can maintain a more aggressive “wings-level” orientation. Problems were encountered with the laser altimeter for altitude reference, however, the aircraft roll feedback routine was greatly improved for CBLAST-Low.

N3R participated in a three-week CBLAST-Low pilot study over the waters south of Martha’s Vineyard from late July to early August 2001. A total of 20 missions (~52 flight hours) were flown out of the Martha’s Vineyard Airport. N3R flew numerous low-level flux legs over several surface-based assets. These include the Martha’s Vineyard Coastal Observatory (MVCO), 3D SST array, R/V *Asterias*, and the Air-Sea Interaction Buoy (ASIMET). Numerous profiles were also acquired to document the vertical structure of the MABL. Fig. 2 is an example of N3R’s flight track conducted on 01 August 2001 over the ASIMET buoy (“spirograph pattern”) and the R/V *Asterias* (east-west legs).

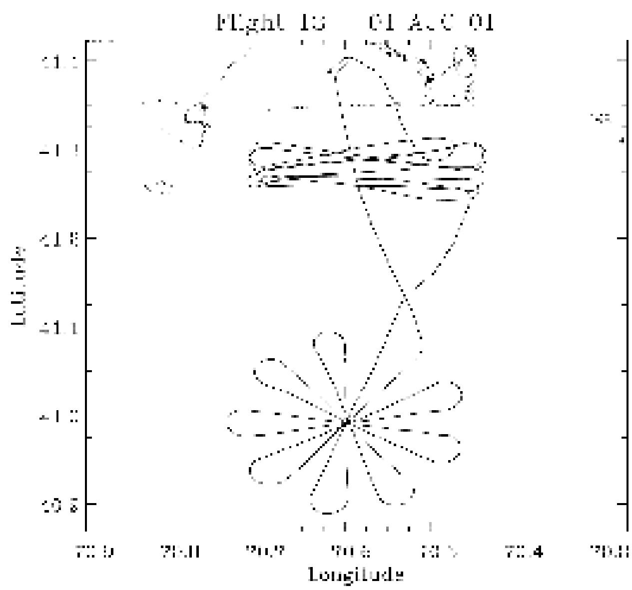

Fig. 2. Example of N3R flight track.

RESULTS

Final post-flight calibrations are being applied to the N3R data set and preliminary data analysis has begun. Contour plots of sea surface temperature and air temperature (Fig. 3) were constructed from a so-called “spirograph” pattern flown by N3R on 29 July 2001 between 0800 and 0900 local time. The region was dominated by a high pressure system with mid- and high-level clouds moving into the area with very light and variable winds. N3R flew 10-m high flux legs about 20 km in length with the center of the pattern over the ASIMET buoy. Note that the ASIMET buoy is located along the edge of a SST front with warmer water to the southwest and west of the buoy. SST temperature differences of 2° to 3° C were observed over the course of just a few kilometers. As expected, air temperature at 10 m reflects the forcing by the SST front with warmer air to the southwest and west and colder air to the northeast of this sample region. Differences of up to 2° C in air temperature were observed in this case study. This strong SST forcing of the MABL has direct implications on the turbulent flux interpretation and parameterization.

IMPACT/APPLICATIONS

The data acquired by N3R will have a direct impact on our understanding of energy exchange processes across the air-sea interface in the light-wind MABL. Until now, very little turbulent flux data existed for a light-wind MABL. N3R has simultaneously acquired atmospheric turbulence and ocean surface data under a variety of stability regimes in a light-wind MABL. These data will used to improve parameterizations describing air-sea transfer processes.

TRANSITIONS

N3R data will be used by other CBLAST-Low investigators for surface-based intercomparisons and for model initialization and testing.

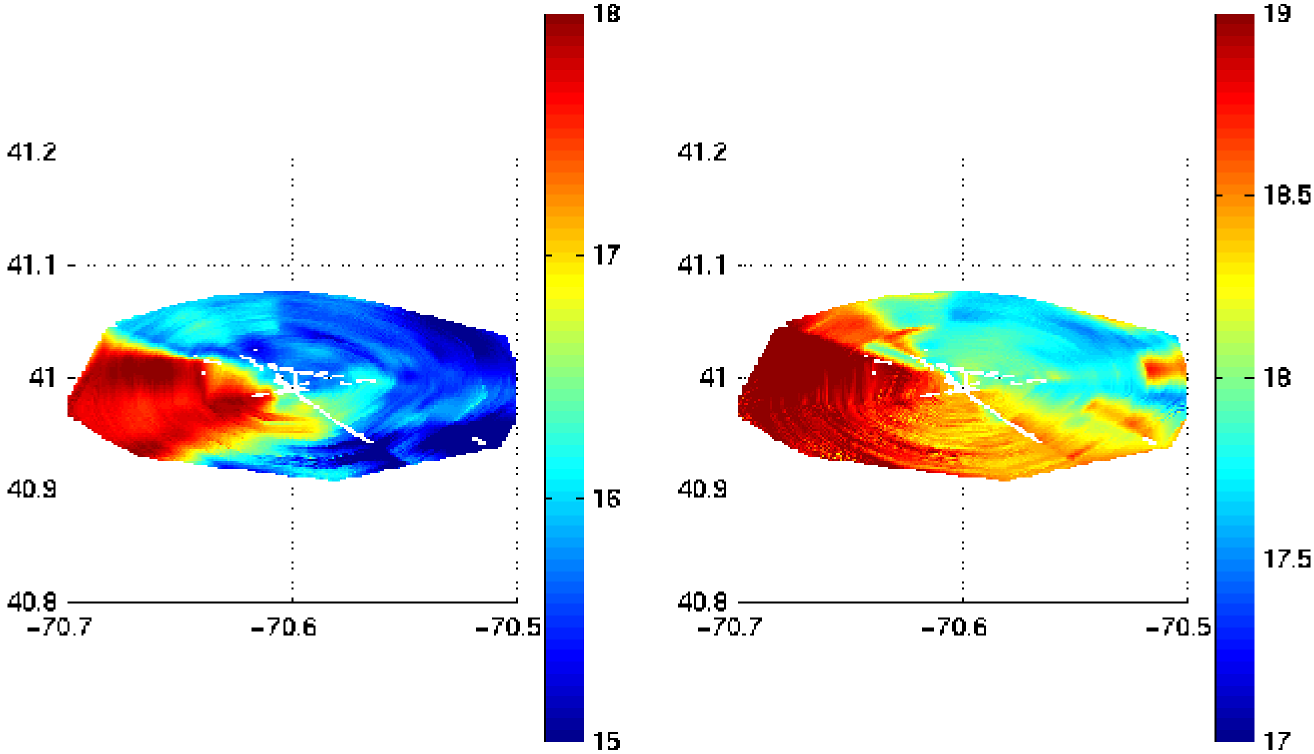

Fig. 3. SST (left) and air temperature (right) acquired by N3R on 29 July 2001 between 0800 and 0900 local time centered over the ASIMET buoy.

RELATED PROJECTS

Data acquired by N3R in light wind regimes during the Wave Profile Experiment (WAPEX) and the Shoaling Waves Experiment (SHOWEX) are being used to augment data acquired in CBLAST-Low.

PUBLICATIONS

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